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The development of a modelling solution to address manpower and personnel issues using the IPME

Wenbi Wang

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Abstract

The addition of occupational information into a human performance modelling environment enables the creation of human performance models that are sensitive to operator's occupational attributes. Such models can be used to address manpower and personnel issues frequently encountered in military system design and evaluation. A recent applied research project was conducted to incorporate the Canadian Air Force occupational data into the Integrated Performance Modelling Environment (IPME). This project expanded Defence Research and Development Canada (DRDC)'s modelling capability and enabled analysts to use modelling and simulation to examine manpower and personnel solutions in future Canadian Forces (CF) acquisition projects. The report recaps major activities in this project, including occupational data integration, software implementation, and the application of the occupational data in IPME models.

Résumé

L'ajout de données sur les groupes professionnels militaires dans un environnement de modélisation du rendement humain permet de créer des modèles de rendement humain qui sont adaptés aux caractéristiques professionnelles d'un opérateur donné. Ces modèles peuvent être utilisés pour résoudre les problèmes liés à la main d'œuvre et au personnel que l'on rencontre souvent lors de la conception et de l'évaluation des systèmes militaires. On a récemment mis en œuvre un projet de recherche appliquée afin d'intégrer des données sur les groupes professionnels militaires des Forces canadiennes (FC) dans l'Environnement intégré de modélisation du rendement (EIMR) / *Integrated Performance Modelling Environment (IPME)*. Ce projet a permis d'augmenter les capacités de modélisation de Recherche et développement pour la défense Canada (RDDC) et a permis aux analystes d'utiliser la modélisation et la simulation pour examiner les solutions aux problèmes de main d'œuvre et de personnel dans les futurs projets d'acquisition des Forces canadiennes (FC). Le rapport récapitule les principales activités menées dans le cadre de ce projet, y compris l'intégration des données sur les groupes professionnels militaires, la mise en œuvre du logiciel et l'application des données sur les GPM dans les modèles de l'EIMR.

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Executive summary

The development of a modelling solution to address manpower and personnel issues using the IPME:

Wenbi Wang; DRDC Toronto TR 2010-138; Defence R&D Canada – Toronto; November 2010.

Introduction or background: Manpower and personnel are sub-domains of Human Systems Integration (HSI). The issues associated with manpower and personnel, such as crewing effectiveness, are an integral component in system design and are often encountered in Canadian Forces (CF) acquisition projects. One viable approach to resolve such issues is by using modelling and simulation. However, the existing modelling capabilities at Defence Research and Development Canada (DRDC), particularly those associated with human performance modelling, were limited prior to the current project. This was reflected in a capability gap that the occupational characteristics of an operator could not be precisely represented in a model. With a goal to resolve this limitation, an applied research project was conducted to incorporate the Canadian Air Force occupational data into the Integrated Performance Modelling Environment (IPME).

Results: The project consisted of four main activities:

- The identification of occupational data that are relevant to human performance modelling, particularly to IPME models;
- The integration of the occupational data into the modelling environment;
- The development of methodologies for applying the occupational data in human performance models;
- A simulation experiment that verifies and validates the newly developed modelling capability.

As the project unfolded, the CF military occupational specifications were identified as the main data source for occupational information and the data were classified into three categories based on their relevancy to computational human performance models. Major Air Force occupational specifications were converted into relational databases and a java program was created as a bridge application that linked IPME to the databases. IPME itself was further developed to accommodate the occupation information. Data security and interface usability were emphasized during the entire data integration and software implementation effort.

Significance: With the newly developed capability, it is feasible now to create IPME models that are sensitive to an operator's occupational assignment. This enables analysts to study manpower and personnel options using either gap analyses or conventional system performance metrics like mission completion time, system failure rate, and operator workload. This capability directly supports simulation-based acquisition and it paves a way for using modelling and simulation to address the Human Resources (HR) cycle of activities.

Sommaire

The development of a modelling solution to address manpower and personnel issues using the IPME:

Wenbi Wang; DRDC Toronto TR 2010-138; R & D pour la défense Canada – Toronto; Novembre 2010.

Introduction ou contexte : La main-d’œuvre et le personnel sont des sous-ensembles de l’intégration des systèmes humains. Les questions liées à la main d’œuvre et au personnel, telles que l’efficacité dans la mise sur pied des équipes, font partie intégrante de la conception des systèmes, et on y est souvent confronté dans les projets d’acquisition des Forces canadiennes (FC). L’une des approches viables à utiliser pour résoudre ces questions est la modélisation et la simulation. Cependant, les capacités de modélisation actuelles de Recherche et développement pour la défense (RDDC), particulièrement celles qui sont associées à la modélisation du rendement humain, étaient limitées avant ce projet. Cela était dû au fait que les caractéristiques professionnelles d’un opérateur ne pouvaient pas être représentées avec précision dans un modèle. Dans le but de résoudre cette contrainte, on a mis en œuvre un projet de recherche appliquée afin d’intégrer les données professionnelles de la Force aérienne du Canada dans l’Environnement intégré de modélisation du rendement (EIMR).

Résultats : Le projet englobe quatre activités :

- la détermination des données sur les professions qui sont pertinentes pour la modélisation du rendement humain, plus particulièrement pour les modèles de l’EIMR;
- l’intégration des données sur les professions dans l’environnement de modélisation;
- l’élaboration de méthodologies pour l’application des données sur les professions dans les modèles de rendement humain;
- un essai de simulation pour vérifier et valider les capacités de modélisation nouvellement développées.

À mesure que le projet évoluait, les descriptions des groupes professionnels militaires des FC ont été jugées comme les principales sources de données sur les groupes professionnels militaires et les données ont été classifiées en trois catégories en fonction de leur pertinence en ce qui concerne les modèles informatiques du rendement humain. On a converti les principales descriptions des groupes professionnels militaires de la Force aérienne en bases de données relationnelles et on a créé un programme java servant de passerelle entre l’EIMR et les bases de données. L’EIMR lui-même a été élaboré davantage en tenant compte des données sur les groupes professionnels militaires. Durant tout le processus d’intégration des données et de mise en œuvre du logiciel, on a mis l’accent sur la sécurité des données et la convivialité de l’interface.

Importance : Grâce aux nouvelles capacités développées, il est maintenant possible de créer des modèles d’EIMR adaptés aux tâches professionnelles d’un opérateur donné. Cela permet aux analystes d’étudier les possibilités concernant la main d’œuvre et le personnel à l’aide d’analyses des insuffisances ou de mesures conventionnelles du rendement des systèmes telles que le temps d’exécution de la mission, le taux de défaillance du système et la charge de travail des opérateurs.

Cette capacité appuie directement l’acquisition fondée sur la simulation et ouvre la voie à l’utilisation de la modélisation et de la simulation pour le cycle d’activités des ressources humaines (RH).

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1. Introduction

The introduction of new military hardware into the Canadian Forces (CF), especially those embedded with emergent technologies, often calls for systematic methods to evaluate their associated manpower and personnel (M&P) implications. From individual operator definition to crewing effectiveness, Defence Research and Development Canada (DRDC) has been involved in many studies to examine M&P related issues across a variety of acquisition projects [1-4]. These issues represent an important component in system design and evaluation because they affect not only whether the right person(s) can be identified to operate, support, and maintain a system, but also their impact on the system's life-cycle cost.

According to the United States (US) Army's Manpower And Personnel Integration (MANPRINT) program [5], manpower and personnel are two sub-domains of Human Systems Integration (HSI)[1] (as illustrated in *Figure 1.1*). While the general objective of HSI is to ensure that military systems are developed with an enhanced combat capability by considering human capabilities and limitations in the design [6], the two sub-domains have their specific goals.

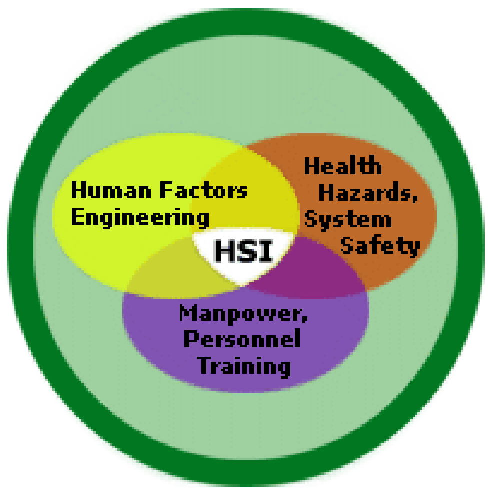

Figure 1.1: Human systems integration (HSI) and its sub-domains.

The manpower sub-domain is concerned with the number of military and civilian personnel required and potentially available to operate, maintain, sustain, and provide training for a military system. It deals with the number of personnel spaces and available people. One of the main concerns in this domain is to evaluate the manpower required and/or available to support a new system and subsequently considers these constraints to ensure the system's subsequent human resource demands do not exceed the projected supply. Such issues are examined in various operational context including peacetime, conflict and low intensity operations [5].

The personnel sub-domain deals with operators' cognitive and physical characteristics required to operate, maintain, and sustain materiel and information systems. It considers the human aptitudes, skills, and experiences required to perform the jobs of operators, maintainers and support personnel. Its main concern is to match the right person with the right job by examining

[1] The Canadian definition of HSI differs slightly from the one provided by MANPRINT, and in particular, it combines manpower and personnel into a single domain.

individual's cognitive and physical capabilities to achieve optimal system performance. Such capabilities are normally examined in relation to operators' knowledge, skills, and abilities [5].

Conventionally, manpower and personnel issues are often addressed by examining existing solutions for similar systems and/or a trial-and-error method based on human-in-the-loop tests. Such an approach is acceptable for designing systems that involve evolutionary advancement or incremental upgrades. It becomes insufficient for new systems that adopt novel operating concepts. For the latter case, modelling and simulation (M&S) is proposed as a potential alternative solution. Compared with the conventional approach, M&S has the advantages of being suitable for application in the early stage of system design, e.g., before prototypes become available for testing, and is especially useful for the acquisition of first-of-its-kind systems.

Over the past decade, DRDC has spent significant effort and resources on the development of a human performance modelling software, the Integrated Performance Modelling Environment (IPME). Conventionally, IPME models are created to examine the machine aspect of a system in which human performance is viewed as a dependent variable affected by different equipment (e.g., system interface) configurations. A DRDC applied research project, entitled "*The addition of the Canadian Air Forces occupational characteristics into IPME"*, was conducted to explore the use of human performance models to address the human aspect of system design, particularly the manpower and personnel solutions, in future CF acquisition projects. This report provides a summary of this project.

1.1 Manpower and personnel issues in system design and evaluation

In the design of a system that involves human operators, a common manpower concern is the specification of its crew size, for example, the number of sailors required to operate a frigate or the size of a team to fly Uninhabited Aerial Vehicles (UAVs). Such decisions have to consider a wide range of factors including the projected operational environment, mission criticality, consequences of failure, readiness of the crew, and in many cases, a budgetary constraint.

In the past, the manpower requirement often emerges as an outcome of equipment design. In many projects, hardware and software specifications are made first and crewing analyses are then conducted to identify a proper level of manning to fit into the system. With the rapid advancement of automation technologies, however, many tasks traditionally allocated to the human can now be assigned to automated systems. In other words, technologically it has become increasingly feasible to replace a human operator with some form of automation. At the same time, with the recognition of the significance of manning cost, there is a new trend to treat the manpower requirement as a driver in system design. This is most obviously reflected in many recent naval platform acquisitions where crewing reduction has been a constant theme across many projects [7-9]. The manpower requirements become an important design goal and serve as a justification for equipment choices.

Such a shift emphasizes the need to examine the manpower solution as an integral component in system designs. As a design driver, manpower requirements may lead to the change of the concept of operations (CONOPS) and the adoption of emergent technologies. The quality of a manpower solution therefore should be evaluated in the context of these design options and in terms of its impact on overall system effectiveness.

Personnel concerns are reflected in the physical and psychological requirements of individual operators, such as the specification of knowledge, skills, and ability requirements for performing designated jobs, and the design of operator training programs to maintain a proper level of proficiency.

The adoption of automation in modern military systems has many implications on personnel decisions. As a general rule of thumb, automation tends to transform an operator from a doer to a monitor. For example, a pilot has become a flight manager because the task of flying a modern jet nowadays resembles more closely that of a desk officer for whom a large portion of the task is to interact with an automated computer system. The physical effort required for operating such a system is much reduced; however, this comes with an increased cost in cognitive demand. For system designers, it is important to ensure that the knowledge and skills required to use the system are set at such a level that a sufficient pool of operators is available or can be trained to fulfill the projected demand.

Another consequence associated with automation use is operator deskilling, particularly the type of skills required to manually complete a task when automated aids become unavailable. For highly reliable automated systems, the conventional wisdom that in situ work training will always enhance an operator's knowledge and skills should be accepted with caution. Operators may over rely on the automation (i.e., complacency), and their knowledge and skills to manually operate the system may be reduced after a prolonged use of the automated system [10-11]. This is particularly problematic for military systems given the potentially hostile environment where these systems are deployed. Currently, operator deskilling (and its prevention) is still treated as an academic topic and is discussed as a challenge to automation designers. However, its implication on the personnel domain is obvious. How should one design an automated system so that de-skilling can be reduced? How should one develop effective training regimes that maintain and enhance operators' proficiency levels? These are examples of personnel concerns to be answered in the design process.

1.2 Modelling and simulation (M&S) as a solution

It is feasible and desirable to use M&S to resolve many of the manpower and personnel issues described above. Based on the general paradigm followed by the human performance modelling community, after mission tasks and operator capabilities are represented in a computational model, it is possible to examine different configurations of operators, either holistically as a team or independently as a collection of individuals, and their impact on mission performance. The approach preserves most benefits commonly associated with the use of M&S, such as cost-effectiveness due to its early insertion into the cycle of system design [12]. Two advantages are particularly worth highlighting.

First, a common challenge shared by many acquisition projects is to handle the task-artefact cycle, a dilemma faced by system designers and developers [13]. Ideally, the requirements for a new system should be based on an understanding of the ways in which operators will use the new equipment. However, for complex systems or systems to be deployed in complicated operational settings, such requirements are difficult to be predicted a priori. As a result, many new systems, designed based on existing operational and technical conditions which unfortunately are altered after the deployment of the new systems, may fail to achieve their original design goals. Since human systems are often complex, the problem is frequently manifested in the manpower and personnel solutions. This is a wicked problem [14] that can not be easily resolved, however the use of M&S can address it to some extent, since more cycles of testing can be squeezed into the

development timeline using simulation and a wider range of deployment conditions can be included to test the robustness of the system.

Second, this approach is in-line with a broader North Atlantic Treaty Organization (NATO) effort to encourage simulation-based acquisition [15-16]. Wellwood & Drouin's recent review on M&S tools revealed a lack of capability to address the human aspect of issues in system design [17]. Since manpower and personnel are integral components in a system solution, it is important to develop modelling capabilities to handle such issues.

Prior to this project, the human performance modelling capability in DRDC was not sufficient to support manpower and personnel modelling. One recognized obstacle was the lack of precision in operator representation. Since many models were conventionally constructed to evaluate the machine aspect of a system, the operators represented in such models were often generic in nature and did not possess the attributes required in manpower and personnel solutions. Three areas of development were identified to resolve this issue:

1. Increase the precision in operator representation. Since the CF manages its members based on military occupations, it is critical to create operator models that are distinguishable by their occupational characteristics.

2. Enhance task representation. To create performance models that are sensitive to operator occupational characteristics, it is necessary to describe the operator's work (i.e., tasks) using attributes that reflect such occupational characteristics.

3. Develop performance metrics and analysis methods to diagnose and/or evaluate manpower and personnel solutions.

In this project, the IPME was identified as a preferred platform to implement these ideas.

1.3 IPME and the current capability gap

The IPME is an integrated software environment for modelling human behaviour and studying human and system performance [18-19]. In brief, an IPME model often consists of several components, including a task network, a crew model, performance shaping functions and an environment model. System performance, as measured by task completion time, error rate, or operator workload, can be estimated by executing the model based on a discrete-event simulation engine MicroSaint™ (Alion Science and Technology, MA&D Operation, 4949 Pearl East Circle, Suite 300, Boulder, CO 80301, USA). A number of workload algorithms have been implemented in the IPME to examine operator cognitive demand and diagnose potential system performance breakdowns caused by information overloading [20].

The construction of an IPME model typically starts with the formation of a list of research questions. These questions are then used to determine the appropriate level of abstraction in model representation, as well as the Measures of Effectiveness (MOEs) and Measures of Performance (MOPs). Operator work is described in the form of a task network, with each task representing a discrete activity and between-task connectors indicating the logical and/or temporal sequence between the activities. Operators themselves are represented in a crew model and can be assigned to a human task in the task network. Depending on the objectives of a study, performance moderators can be specified in an environment model, with their impact on system performance described using performance-shaping functions. In cases where collaboration with

other models is required, the IPME allows analysts to set up external models to exchange data using a standard network protocol.

Besides these component models, IPME provides a battery of functions that are frequently used in a simulation. For example, it accepts user-defined variables or functions, and allows analysts to embed C style scripts in a model. Scenario events can be created to dynamically adjust the variables during a model's execution. The simulation outputs are recorded in the form of either standard IPME reports or customizable data files using system snapshots. For the complete information on IPME modelling, readers are referred to its user's guide [21].

The use of the IPME to support manpower and personnel modelling is desirable. First, it enables an analyst to examine manpower and personnel options in light of their impact on system performance. Using the workload algorithms in the IPME, for example, it is possible to create or diagnose a manpower solution based on the projected cognitive demand on each operator. Second, the IPME has been developed as a flexible modelling platform and it supports a modular approach in model construction. Self-contained micro models can be developed either as a component model within the IPME or as an external model that can communicate, e.g., exchange data, with an IPME model. These features make the IPME a preferred platform in the current project to explore different implementation options.

Prior to this project, operators in an IPME model were represented primarily by their biological and psychological attributes, and their tasks are described in terms of demand in time and cognitive resources. Such a level of representation is sufficient for workload assessment. However, without a description of an operator's occupation, model outputs can not be easily linked to manpower and personnel decisions. The critical obstacle, as identified in this project, was the lack of precision in the operator model, particularly the lack of representation of operator's occupational characteristics. As a result, the main effort in this project was to expand the IPME's capability by identifying and integrating the CF occupational data into the modelling environment and creating methodologies for applying such data in human performance models.

The following list summarizes the major project activities:

1. Analyze the CF MOS and identify occupational data that are relevant to human performance modelling.

2. Create a framework for accommodating the occupational characteristics in computational human performance models;

3. Expand the IPME to incorporate the occupational data;

4. Develop methodologies for creating human performance models that are sensitive to the occupational characteristics; and

5. Verify the effectiveness of the modelling solution in a simulation exercise.

Much of the project activities were supported by Alion Science and Technology, MA&D Operation. Although the research and development effort in this project was applied, tested, and discussed in the context of the IPME, the methodology is generally applicable to other human performance modelling platforms.

1.4 An overview of this report

This report is a companion document to the contract report produced by Alion Science and Technology [22]. While the contract report provides a detailed account of major project activities and describes *what* had happened in the project, this report intends to address *why* the chosen integration approach was selected, *how* the integration method was decided, and discuss M&P modelling issues from a broader perspective.

This report consists of five sections. The current section describes the context of this project, and highlights the gap in DRDC's current M&S capabilities to support manpower and personnel modelling. Each of the next three sections covers a major milestone in this project, including occupational data identification (Section **2**), data integration and software implementation (Section **3**), and the application of the occupational data in IPME modelling (Section **4**). A general discussion, including the project limitations and future research directions, is provided in Section **5**.

2. Occupational data identification

The first major task in this project was to identify occupation information that could be used in computational human performance models. The task was achieved by a close examination of the existing CF MOS.

Military occupations are the fundamental groupings of CF personnel. Each occupation comprises related jobs that have similar duties and tasks, and require similar competencies. Each CF occupation typically includes one or more entry-level jobs, followed by jobs at several subsequent developmental levels. Some occupations may be further divided into sub-occupations. In other cases, several occupations may be grouped together to form a career field. The entire framework of career fields, occupations and sub-occupations that describes the interrelationships of military jobs creates an MOS.

According to the Canadian Forces MOS policy, MOS is formally defined as "*the arrangement of the CF jobs into structural elements, consisting of military career fields, military occupations and military occupation specialties that collectively provide the necessary management framework for the Human Resource (HR) cycle of activities across all components of the CF, throughout the spectrum of conflict.*" Since its creation in the early 1970s, MOS has formed the foundation of the CF HR management system. It supports important HR activities including personnel production planning, recruiting, professional development, assignment and personnel management.

An important component of MOS is the Occupational Specifications (OS), which are documents describing the minimal qualifications required for entry into an occupation, the common job performance requirements for each occupational qualification level, and the career, training and employment patterns for its members. Since the OS describes the common set of occupational attributes shared by its members, it was regarded in this project as the primary source of data for integration into IPME. Much of the initial project effort was spent on categorizing the OS data based on their relevancy to computational models. This section will describe the OS data and the rationale used in the categorization process.

During the time when the current project was conducted, the Department of National Defence (DND) also initiated a Military Occupational Structure Analysis, Redesign, and Tailoring project (MOSART) to modernize the CF's military occupational structure. MOSART had a significant influence on the current project since it not only redefined the CF occupations, but also the policies to manage the CF personnel. Due to its important impact on future manpower and personnel management, a brief review of MOSART is first provided in this section.

2.1 MOSART

The general objective of MOSART was to develop an MOS that attracts highly skilled and motivated people by expanding the range of career opportunities and maximizing the efficiency of the CF HR management system. This objective was supported by three specific project activities:

1. To establish a new MOS that enhances operational capabilities and contributes to increased personnel retention through the use of broader career fields;

2. To revise supporting policies and procedures related to the MOS; and

3. To create a master implementation plan that depicts the transition to the new structure across the CF.

The new MOS reflects a shift of HR management principles from a position-based to a job-based system. Previously, the CF managed its work through approximately 85,000 positions. Following the principle of job-based management, these positions are consolidated into 8,000 to 10,000 military jobs based on their work requirements, as illustrated in *Figure 2.1*. This allows for a more effective and efficient way to manage personnel across the CF and is considered as a key step towards the creation of a total force.

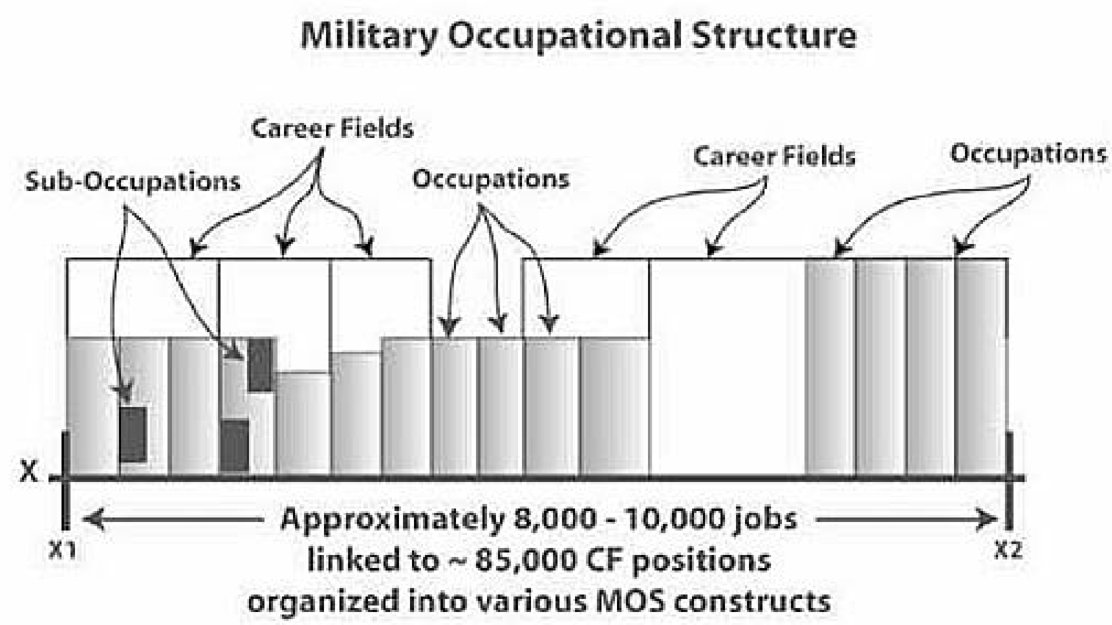

Figure 2.1: An illustration of the grouping strategy used by MOSART to revise the existing MOS. (Adapted from [23])

To achieve this goal, MOSART followed a "world of work" hierarchy (see *Figure 2.2*) and started with an examination of the overall CF work requirement at the job level. Once jobs were identified and defined, they were grouped into larger occupational constructs, such as occupations, sub-occupations, and career fields, to form the new MOS.

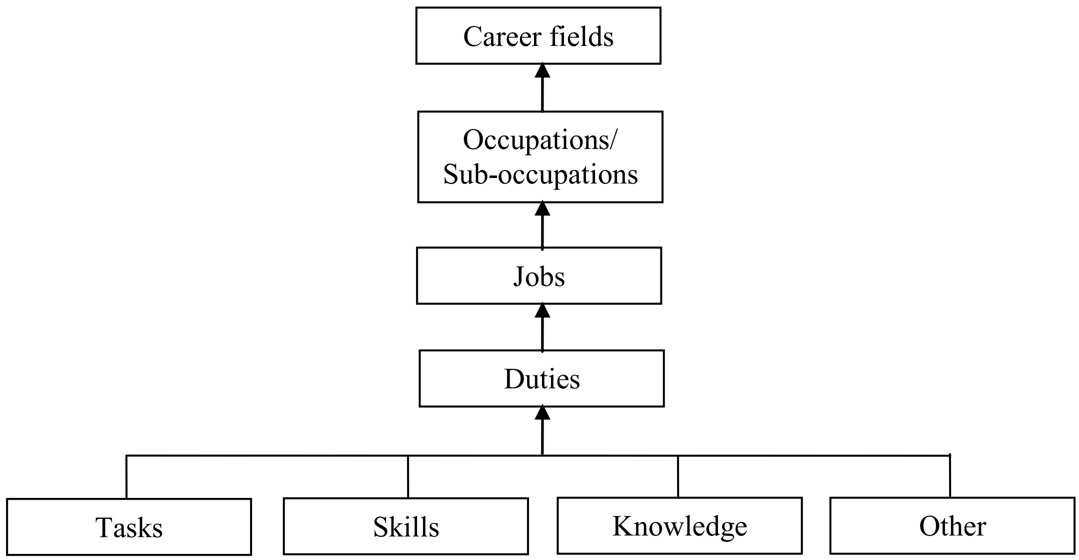

Figure 2.2: The "world of work" hierarchy, adapted from[24].

The resultant new MOS reflects many changes. For example, a five-digit occupational coding system, i.e., the Military Occupational Structure Identification Code (MOSID), replaced the original three-digit Military Occupational Code (MOC); more specific competency scales were introduced to measure skill and knowledge requirements associated with each occupation. At the strategic level, the new MOS supports the creation of integrated professional development plans. For the CF members, the system is more open and transparent, allowing them to gauge their personal qualifications and competencies against existing job inventories, thus providing a clearer picture of professional development requirements, personal goals, and in turn, more control and influence over individual careers. For the current project, the new MOS provides a reference frame for manpower and personnel modelling, and the revised occupational specifications reflect the up-to-date definition of each CF occupation.

It is useful to note that the new MOS was still evolving and MOSART had not completed all its planned occupational analyses while the current project was conducted. Consequently, the occupational data adopted in the project and discussed in this report are provisional in nature. However, this did not affect the validity of the modelling approach explored in this project.

2.2 Occupational specification (OS)

Across the MOS, the CF organizes its members in 103 occupations, as shown in *Table 2.1*. Among them, 35 are officer occupations and 68 are non-commissioned member (NCM) occupations. The information for each occupation, such as duties, responsibilities, qualification requirements, are primarily described in two documents: a general specification (GS) and an OS.

Table 2.1: A complete list of CF occupations
(Retrieved from http://hr.ottawa-hull.mil.ca/dgmc.
The definition of these acronyms is provided in Annex A.)

	Navy	**Army**	**Air force**	**Communication and Services**	**Support**
Officer	MARS	ARMD	AEC	CELE (AIR)	BIO
	MS ENG	ARTY	AERE	INT	CHAP(P)
	NAV ENG	EME	AF ENGR	MPO	CHAP(RC)
	NCS ENG	ENGR	ANAV	PAO	DENT
		INF	PLT	SIGS	HCA
					HSO
					LEGAL
					LOG
					MED
					MUSC
					NUR
					PHARM
					PHY TH
					PSEL
					SOCW
					TRG DEV
NCM	BOSN	ARTYMN AD	AC OP	ATIS TECH	AMMO TECH
	CL DVR	ARTYMN FD	ACS TECH	CE SUPT	BE TECH
	E TECH	CBT ENGR	AES OP	COMM RSCH	COOK
	H TECH	CRMN	AM SUP	CONST TECH	CRT RPTR
	MAR EL	FCS TECH	AVN TECH	ED TECH	DENT TECH
	MAR ENG ART	INFMN	AVS TECH	EGS TECH	MED TECH
	MAR ENG ME	MAT TECH	FLT ENGR	FIRE FTR	MLAB TECH
	MAR ENG TEC	VEH TECH	MET TECH	GEO TECH	MRAD TECH
	NAV COMM	W TECH L	NDT TECH	IMAGE TECH	MSE OP
	NCI OP		SAR TECH	INT OP	MUSCN
	NE TECH(A)			LCIS TECH	POST CLK
	NE TECH(C)			LMN	RMS CLK
	NE TECH(M)			MP	SUP TECH
	NE TECH(T)			PH TECH	TFC TECH
	NES OP			RM TECH	
	NW TECH			SIG OP	
	SONAR OP			WFE TECH	
	STWD				

GS and OS both serve as personnel management and quality control documents.

GS identifies the common military and environment qualification requirements for the CF personnel. There is a separate GS for Officers (OGS) and for NCMs (NCMGS). OS identifies the minimal qualifications required for entry into an occupation, the common job performance requirements for each occupational qualification level, and the career, training and employment patterns for its member. Each occupation has its own OS.

Since the domain of manpower and personnel modelling discussed in this project is within the CF, it is not of interest to represent the shared occupational information, i.e., the GS, in a model. As a result, the project focused on the occupational unique characteristics, i.e., OS data, and their integration into the modelling environment.

Table 2.2: A complete list of the data fields in an occupational specification.

Sections	Sub-sections	
Job identification information	Job code	
	Job title	
	Job abbreviation	
	Rank	
	Job physical environment(s)	
	# Establishment positions	
	Security clearance	
	National occupation classification (NOC)	
Military employment structure	Career field(s)	
	Occupation(s)	
	Sub-Occupation(s)	
	Component(s)	
	Element(s)	
Responsibility	Services	
	Personnel	
	Resources	
	Consequence of error	
Competency	Certifications	
	Qualifications	
	Abilities/Aptitude	
	Other competency components	
Effort	Physical	
	Mental	Attention/Concentration
		Analysis
Working conditions	Work environment	
	Risks to health	
Job performance requirements	Technical	Duty areas
		Tasks
		Knowledge
		Skill
		Abilities/Aptitudes
	Environmental	
	General	

An OS typically consists of three sections that describe:

1. common occupational requirements for its members;
2. a career progression plan in terms of employment opportunities and training requirements; and
3. the expected duties/tasks and the associated skills and knowledge requirements.

A complete list of the data fields is available in *Table 2.2* and graphically presented in *Figure 2.3*.

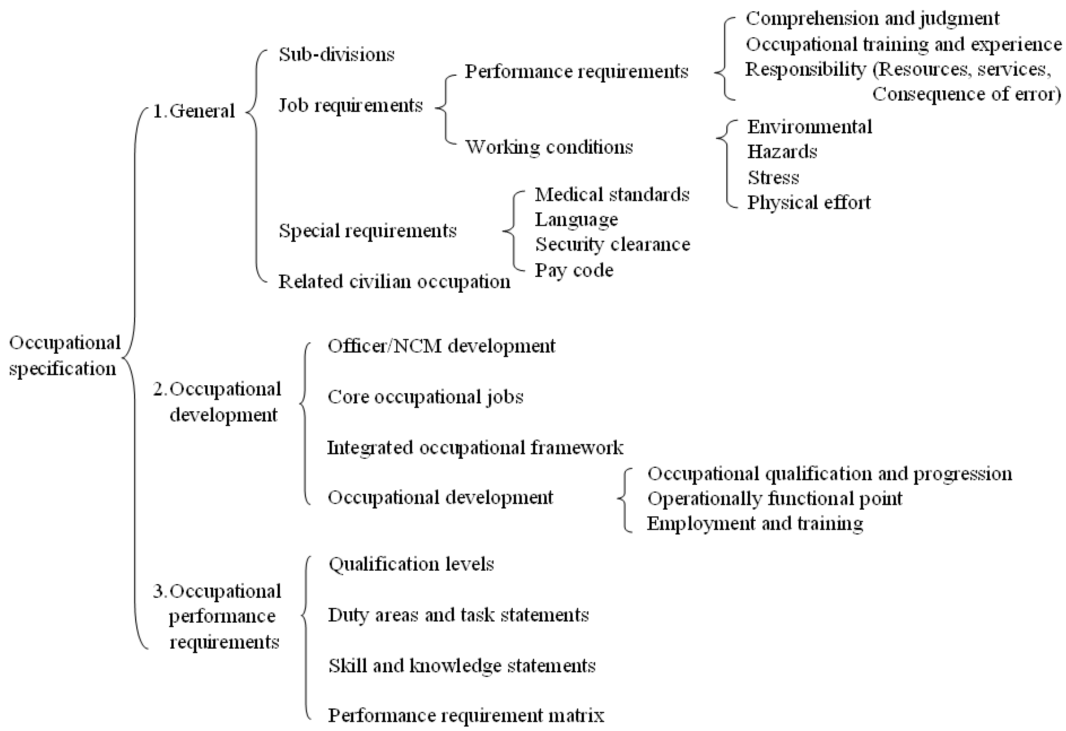

Figure 2.3: The structure of an occupational specification.

Although an OS captures a large amount of information about a CF occupation, only a portion of the data can be applied in human performance models. This is mainly due to two reasons. First, OSs were created to support the HR activities and processes that consist of a wider ranges of manpower and personnel concerns than what human performance models are intended to support in the current project. For example, the career progression plans are typically not a concern in the current military system design, therefore such data are not considered useful in models created to support system acquisition. Secondly, much information in existing OSs is textual descriptions, which prevent their direct use in computational models. This does not imply that qualitative textural data are useless. In fact, such data can assist analysts in model construction (as reflected in the category II data described in the next subsection), however, the impact of these occupational characteristics on model performance outcomes is not possible without some form of numerical instantiation.

2.3 OS data categorization

In order to determine what kind of occupational data can be used in IPME models, the project team classified the OS data into three categories, as summarised in *Table 2.3*. The following questions were used to guide the classification effort:

1. Is the information relevant to the type of human performance models supported by the IPME?

2. Are the data consistent with the IPME's internal constructs for system representation?

3. Are the data numerical or textural in nature? Can they be applied in computational models?

Table 2.3: Three categories of occupational data based on their relevancy to IPME modelling.

OS data	Data type	Category	Links to IPME component models	Note on possible application
Occupational sub-divisions	Textual	II	Crew	For operator definition/classification
Job requirements (Performance requirements)	Textual	II	Crew model, task network	Provide information for the crew and task network models. For example, information on consequences of error may assist the modelling of task failure in the task network model.
Job requirements (Working conditions)	Textual	II	Environment model; Scenario events	Identify performance-shaping factors that can be included in the environment model or manipulated in the scenario events.
Special requirements	Textual	I	n/a	n/a
Related civilian occupation	Textual	I	n/a	n/a
Officer/NCM development	Textual	II	Crew	Operator definition
Core occupational jobs	Textual	II	Task network Crew	Operator definition
Occupational development	Textual	I	n/a	n/a
Integrated occupational framework	Textual	II	Crew	Operator definition
Qualification levels	Textual/ numerical	II	Crew	Operator definition
Duty areas and task statements	Textual/ numerical	III	Crew model, Task network	Operator definition, Task definition
Skill and knowledge requirements	Textual/ Numerical	III	Crew, task network	Operator definition, Task definition
Performance requirement matrix	Textual/ Numerical	III	Crew, task network	Operator definition, Task definition

The first category (I) consists of the OS data that are considered irrelevant to a computational human performance model. Examples of such data include career progression plans and various coding systems (e.g., pay code). These data are not expected to be used in IPME models.

Category II refers to data that are informative for the modelling activity, however their current form does not support direct usage in the IPME. Specifically, these data are textual in nature and consist of descriptions of working conditions, and physical and mental efforts. Access to such data is useful since they provide domain information about an operator's work and potentially can assist model construction. For example, proper stressors can be selected based on the description of an operator's expected work environment conditions. However, the qualitative nature of the data means it is impossible to create computational models that are sensitive to such occupational

characteristics. In the current project, access to the Category II data was created in the IPME; an analyst can browse and search for such data within the modelling environment, but the IPME itself was not modified, i.e., no constructs were created, to accommodate these data.

Category III represents data that can be directly applied in IPME models. More specifically, these are performance requirements for each occupation, i.e., the tasks, skills and knowledge (TSK) requirements and their associated proficiency scores. For each occupation, task statements describe the activities expected to be performed by its members, and skills and knowledge statements explain the required competencies. A numerical rating for each TSK statement is applied to indicate five levels of performance or proficiency requirement. Such data are closely linked to task-network based modelling supported by the IPME. The numerical nature of the proficiency rating enables direct use of such data in computational models. As a result, the TSK data became the focus of the project's integration effort.

2.4 Tasks, skills, and knowledge (TSK) requirements

Due to the significant role the TSK data played in the project's manpower and personnel modelling solution, a closer examination of the data is warranted.

According to the MOS, *task* is a discrete segment of work that has a definite beginning and end, and forms a logical and necessary part of a duty; *skill* is a practised mental or physical activity that requires a measured degree of proficiency. It reflects one's ability to use knowledge effectively and readily in execution or performance; *knowledge* is the minimal theoretical or practical understanding of a subject required to support the performance of duties and tasks. It indicates the fact or condition of knowing something with familiarity gained through experience or association.

A five-level scale is used to rate the TSK proficiency requirement. Level one reflects basic or limited level of proficiency and it consists of an awareness of basic definitions and a requirement for constant supervision. Level five requires comprehensive expert knowledge and complete mastery of techniques and procedures. A complete definition of the proficiency scale is included in *Table 2.4*.

Table 2.4: Five proficiency levels used for rating the TSK requirements.

LEVEL	TASK/SKILL	KNOWLEDGE
1	the level of proficiency required to perform parts or elements of duties and tasks under continuous supervision	an awareness of the basic definitions and concepts associated with a topic or a body of knowledge
2	the level of proficiency normally required to perform duties and tasks under normal supervision	the level of understanding of definitions and basic concepts which enables the relating of this knowledge to job requirements
3	the level of proficiency required to independently and safely perform duties and tasks	the level of understanding of theory and principles of a topic or body of knowledge that is usually gained through formal training and job experience and which enables critical thought and independent performance
4	the level of proficiency	the level of knowledge which is gained from formal

	which usually can be acquired by considerable training and extensive practical job experience	training and education and considerable job experience. This knowledge enables the synthesis/integration of theory facts and practical lessons learned to support the identification of solutions to non-routine problems
5	the level of proficiency indicated by a mastery of techniques and expert application of procedures	a recognized level of expertise, which includes a mastery of theory and application, related to a given body of knowledge

In an OS, TSK requirements are presented in the form of statements and grouped under different duty areas. Each TSK statement is labelled with a unique serial code that distinguishes both its type (T, S, or K) and the duty area it belongs to. For example, as shown in Table 2.5, one of an aerospace control operator (AC OP)'s tasks is to "Conduct passive tracking"; it belongs to Duty Area B "Surveillance" and is labelled as BT0010.

Commonly, as the members move up in their rank, their core jobs differ and their TSK proficiency requirements vary correspondingly. For each occupation, a matrix is used to describe the core jobs within the occupation and their specific TSK requirements. As an example, *Table 2.5* shows a portion of this performance requirement matrix for the AC OP occupation. The complete TSK list consists of 225 statements.

Technically, the quantitative nature of these ratings enables a direct application of TSK data in IPME models. However, it is important to note this rating system is relative in nature. It is originally intended as providing broad parameters for assisting the creation of qualification standards or training plans. Further analysis and validation are needed when applying the data in actual human performance models.

The categorization of the OS data represented the first milestone for this project. The next section describes the follow-up effort to integrate these data into the modelling environment.

Table 2.5: A portion of the performance requirement matrix for the Aerospace Control Operator Occupation.

SERIAL	OCCUPATIONAL REQUIREMENTS	Tracking Tech	Identification	Interface Cont Tech	Data Coord	Data Sys Coord	MCC Tech	Ground Control	Flight Advisor	Air Surv Tech	PAR Cont	Snr PAR Cont	Rescue Coordinator	Mar Flt Adv
	TASK													
	DUTY AREA A - GENERAL													
AT0005	Co-ordinate aircraft control transfer				1			2	2		2	3		
AT0010	Provide information to aircraft		1	1	1			2	2		3	3		
	……													
	DUTY AREA B - SURVEILLANCE													
	……													
BT0010	Conduct passive tracking	2												

BT0015	Maintain air picture	2								3		
	……											
	DUTY AREA C - IDENTIFICATION											
CT0005	Perform safe passage		2									
CT0010	Perform Emergency Security Control of Air Traffic		2				3		2		2	3
	……											
	SKILL											
S0005	Operating RAT	1	1	1						3		
S0010	Strip writing				2			3	3		3	3
	……											
	KNOWLEDGE											
	DUTY AREA B - SURVEILLANCE											
BK0005	Active/passive tracking	2	2	2			1			3		
BK0010	Tabular formats	2	2	2			3			3		
	……											
	DUTY AREA C - IDENTIFICATION											
CK0005	Identification procedures		2							1		
	……											

3. Data integration and software implementation

To effectively use the OS data in an IPME model, the data need to be converted into a digital database and the IPME should be modified to accommodate such data. A general implementation strategy was created in the project to guide the integration effort and it focused on both data security and software usability. Three key design decisions were made, including:

1. the conversion of the OS data into relational databases independent of the IPME;

2. the use of a bridge application to link the IPME to the OS databases;

3. a minimal modification of IPME interfaces to accommodate the use of the occupational data.

This implementation plan emphasized a modular development approach and reflected two main concerns during the execution of the project. First, since the OS data were constantly evolving, especially during the project timeframe when MOSART was actively revising the MOS, the decision to keep the OS databases independent of the IPME was meant to reduce future database maintenance effort. Second, the IPME is commercial software and its user base extends beyond Canada. Since the CF OS data are of interest most likely to its Canadian users, the implementation plan suggested a minimal change of the IPME itself to reduce the impact on non-Canadian users and used a bridge program to link the occupational data to the modelling environment.

3.1 OS databases

The occupational data relevant to IPME modelling, i.e., Categories II and III as identified in Section **2**, were converted into databases. In principle, it is desirable to incorporate the entire dataset into a single relational database so that analysts can browse and compare the data across occupations. However, due to the internal inconsistency that existed in the OS dataset, such a single database solution was not possible. One observed problem was the identical serial labels used for different TSK statements across occupations. As a result, multiple OS databases were created, one for each occupation. Since the current project targeted the Canadian Air Force, only major Air Force occupational databases were implemented.

Generally, an OS database is internally organized in the form of a collection of data tables. Each table contains a subset of the occupational data and consists of multiple fields. In order to satisfy the normal form (NF) requirement, an index field was artificially added to the table when necessary.

The databases were initially implemented in the Microsoft Access and later converted into the PostgresSQL to provide maximal compatibility with the IPME. *Figure 3.1* depicts a complete list of the data tables and their inter-relationships in a typical OS database.

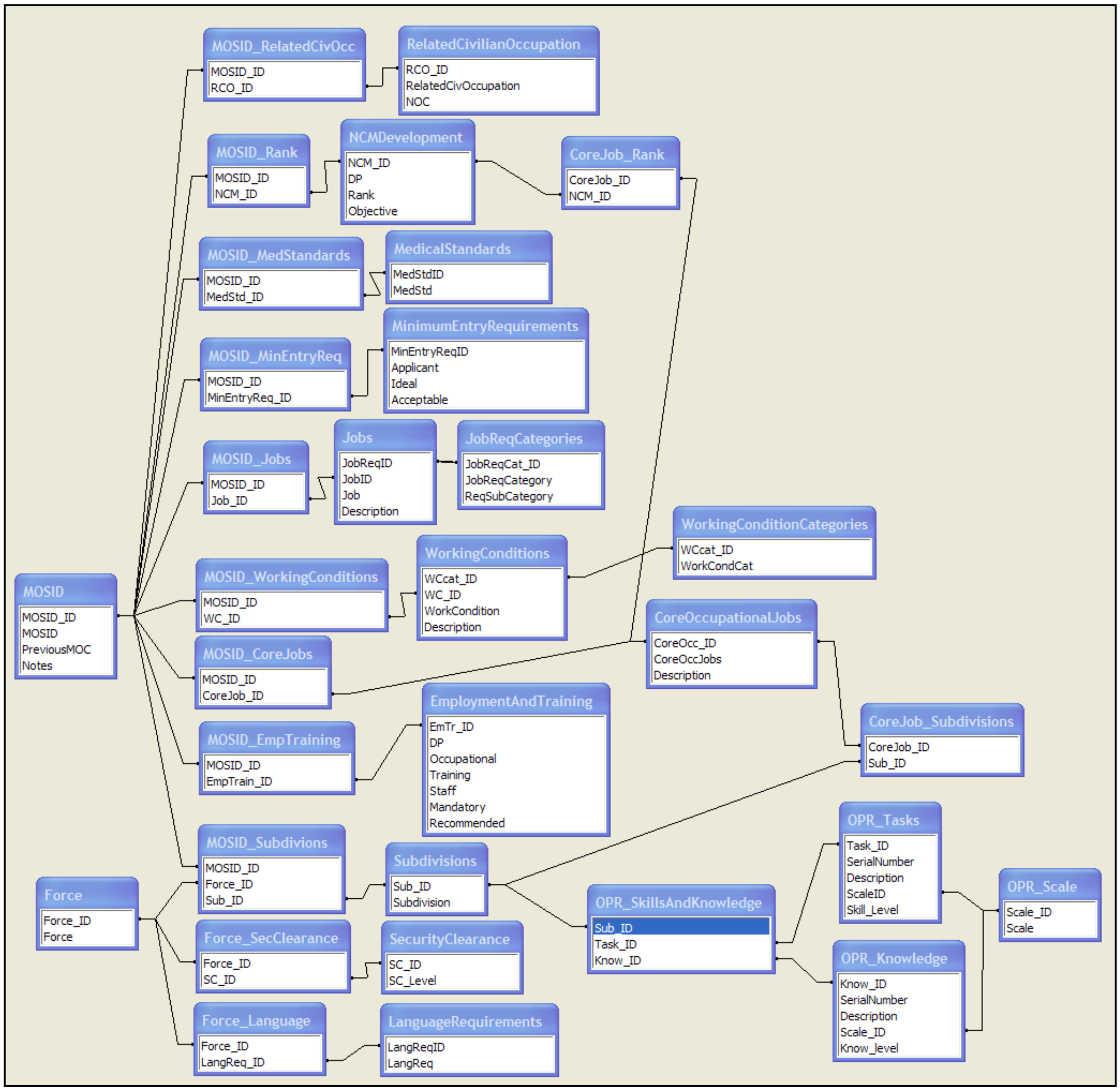

Figure 3.1: Relationships among data tables in a relational OS database.

3.2 A Canadian Air Force MOSID administration tool (CAMA)

The Canadian Air Force MOSID administration tool (CAMA) is a bridge program that serves as a link between the OS databases and the IPME. Technically CAMA is a secure data management application developed in the software language JAVA. It supports the basic databases administrative tasks with an emphasis on the visualization capability and provides a user-friendly interface for analysts to navigate through the OS data. Analysts can use CAMA to browse through the database, modify the data, and conduct keyword search. The data are presented in a hierarchical structure that reflects the relationships among occupations and jobs. For example, when an occupation is specified, its corresponding jobs are automatically ordered and listed. The details of the occupational description can be edited on a consolidated interface. *Figure 3.2* is a sample screenshot from its job viewing/editing window.

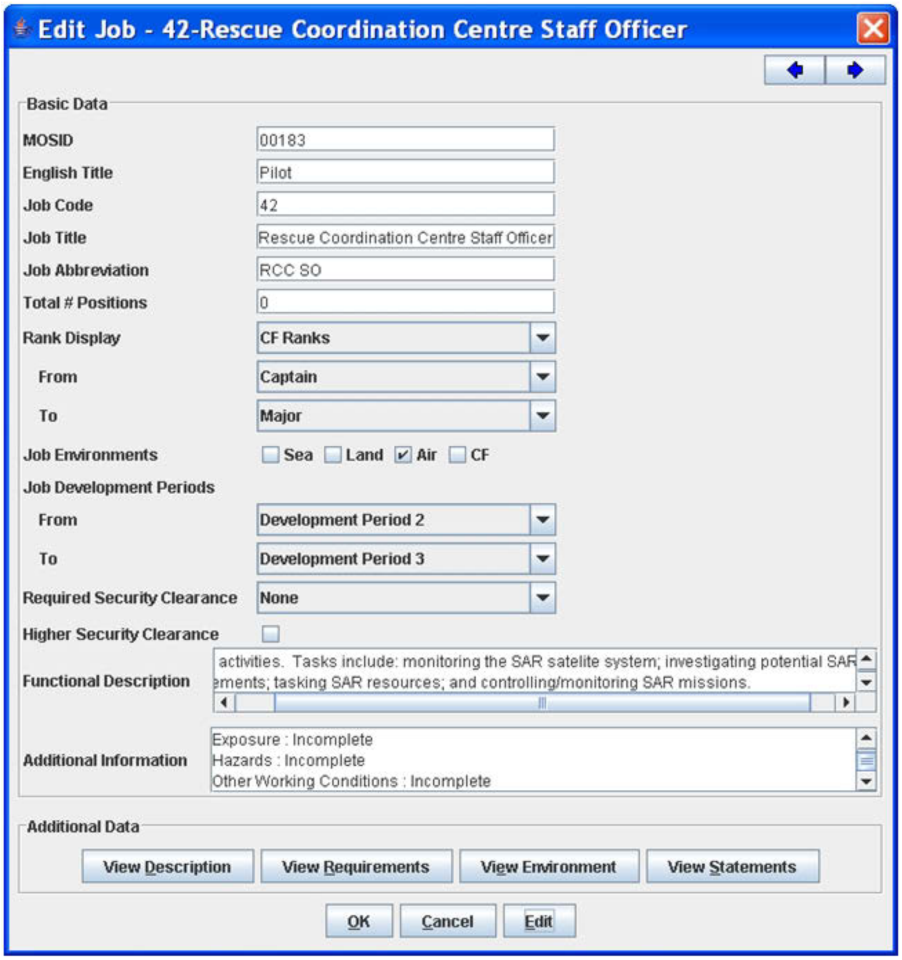

Figure 3.2: A sample screenshot of CAMA.

A search function is also provided by CAMA to allow analysts to quickly locate a piece of information in the database. The search feedback can be further filtered by specifying the occupation and/or job information. The results are presented in a hierarchical format with the lowest level showing the context of the keyword, as illustrated in *Figure 3.3*.

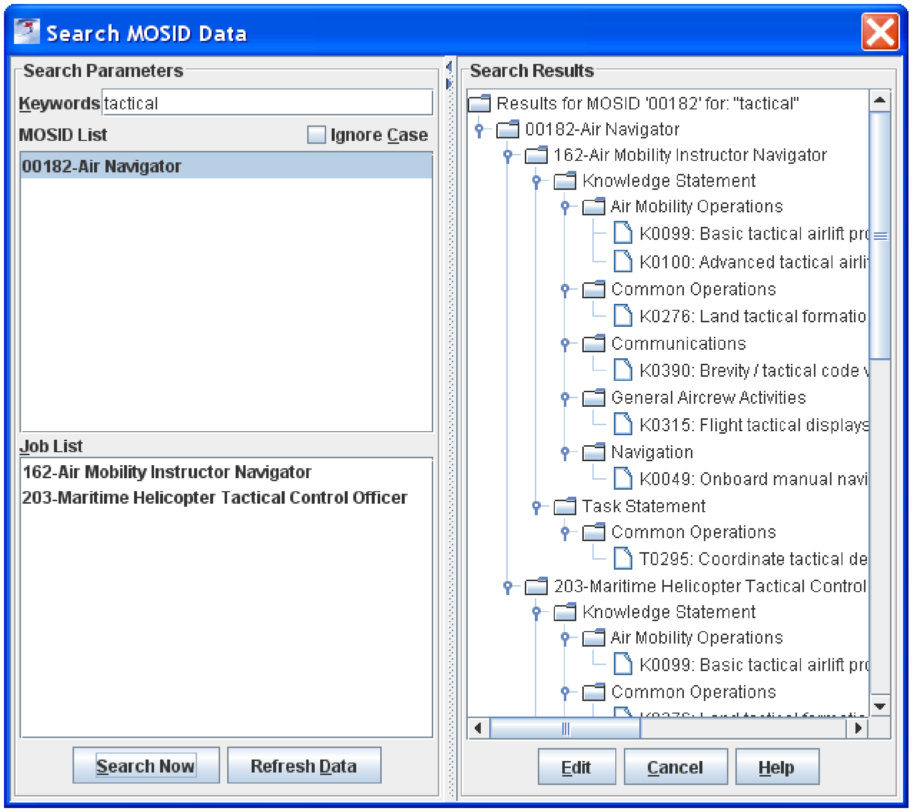

Figure 3.3: Sample keyword search results in CAMA

CAMA was developed to support two different execution modes. First, it has a stand-alone mode in which the program can be run independently of the IPME. In this case, CAMA functions as a database administrative tool that enables analysts to perform common database maintenance tasks (e.g., view, edit, and search). Its interfaces are consistent with the internal structure of the OS data, and essentially it provides a front-end graphical user interface (GUI) for the databases. Second, CAMA can be configured as an IPME plug-in and is initiated from an IPME menu. In this mode, an analyst can use the CAMA to browse and search through the OS databases, and transfer occupational data into IPME models, but its data editing function is disabled to protect the integrity of the OS databases and prevent accidental data modification by either analysts or the IPME. In either mode, CAMA requires a password for database access. The support of such a dual-mode execution enabled software engineers to re-use the core code base and reduced the overall developmental effort.

3.3 IPME modification

As previously explained, one of the software implementation goals was to avoid extensive modification of the IPME. Since access to the OS databases was enabled in CAMA, the IPME development focused on adding an entry point for CAMA and creating internal data constructs for accommodating the occupational characteristics.

A menu entry for initiating CAMA was added to the standard IPME menu (under Tools | User Applications menu). This entry is functional only for users with a special IPME licence which is created and managed by the IPME developer. This license grants privileged access to the

particular copy of the IPME. As an additional layer of protection, a password is required once in every session when a request for OS database access is first made.

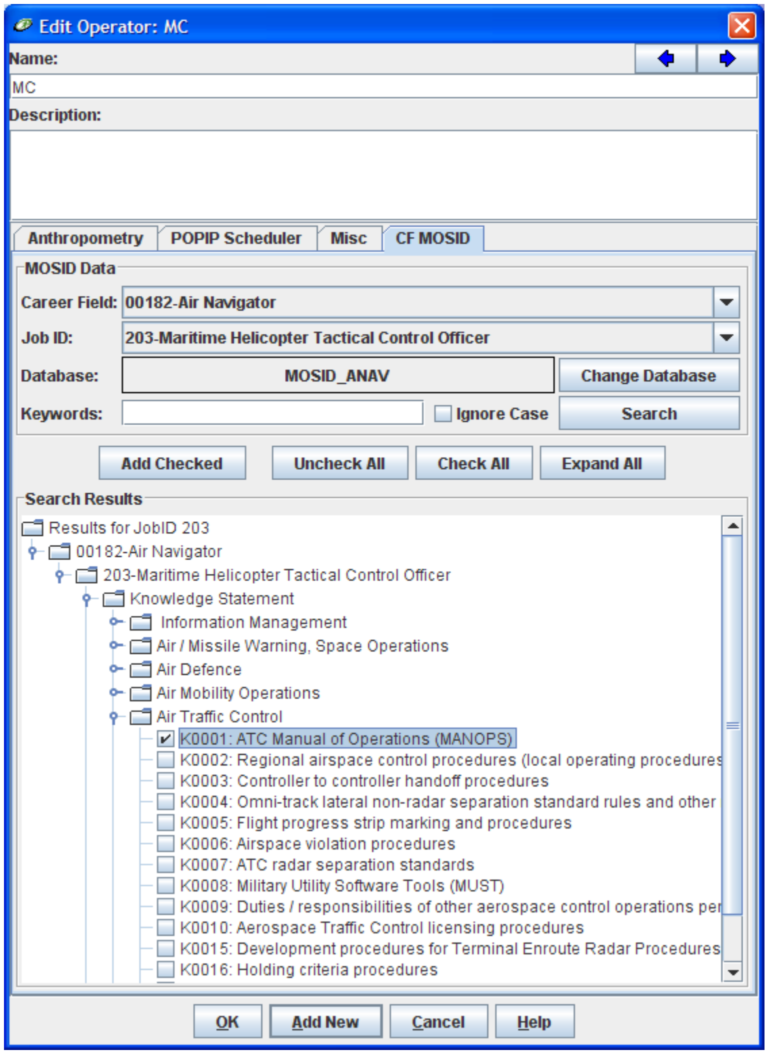

Figure 3.4: A new tab in the IPME operator definition dialogue for specifying occupational characteristics.

In the IPME crew model, the interface for operator definition was modified and a new tab for occupational specification was added. As shown in *Figure 3.4*, an analyst can select the OS database and assign an occupation and a core job to an operator on this new tab. The associated knowledge and skills statements then become available to be selected and populated into the operator model. Although the entire TSK inventory is regarded as relevant occupational characteristics and can in principle be automatically imported into an operator model, this is not implemented primarily based on model efficiency concerns. A CF occupation typically consists of a large number of TSK attributes, for example, the TSK inventory for the AC OP consists of 225 entries. Typically, only a portion of these data is needed in a particular model to address specific research questions. In order to reduce the complexity of a model and improve its execution efficiency, it was decided to provide the analysts with a manual option for selecting an operator’s TSK information.

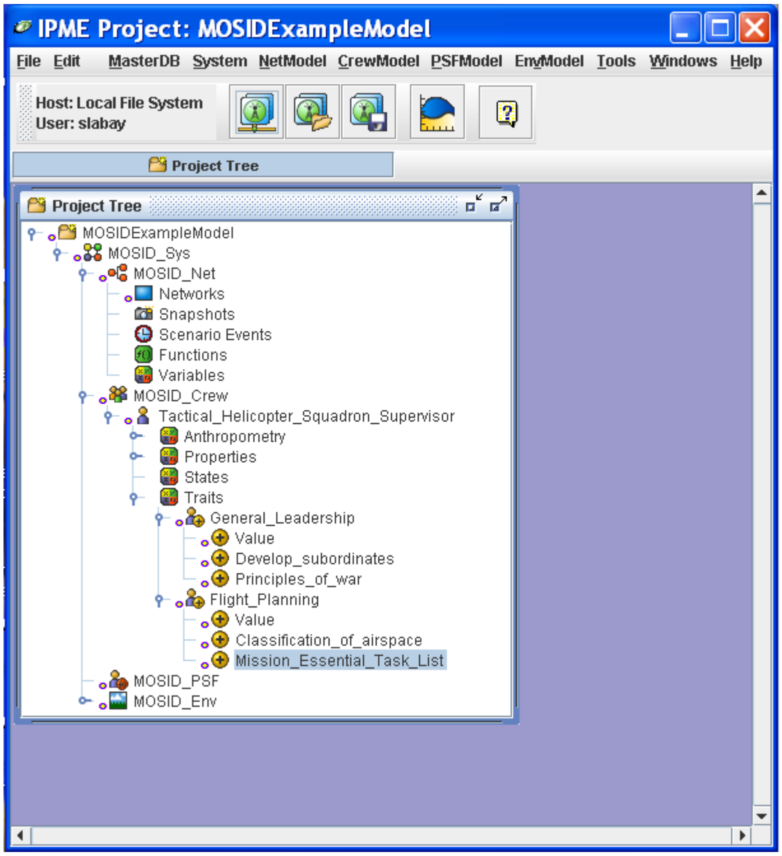

Figure 3.5: An IPME operator model with occupational traits.

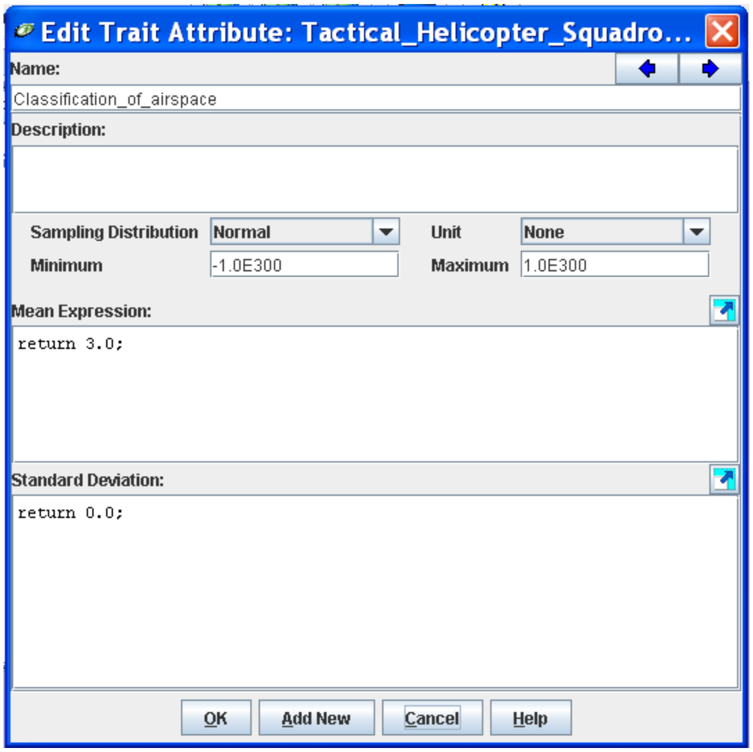

Figure 3.6: The interface for modifying the default proficiency requirement value for an occupation trait.

Once operator definition is completed, the TSK attributes are listed as operator characteristics (see *Figure 3.5*). The naming of each characteristic follows a general schema that involves the use of a *duty area* as the name of an operator characteristic, and the *TSK Statement* as the name of an attribute. By default, the value of each occupational characteristic assumes the proficiency requirement rating obtained from the OS database. Since such a rating is relative in nature (as explained in Section **2**), it can be further adjusted in light of additional empirical evidence. *Figure 3.6* shows the interface for modifying the default TSK proficiency requirement rating.

The development of CAMA and the modification of the IPME create the necessary access to occupational data from the modelling environment. The next section further describes how such occupational data can be applied in an IPME model.

4. Application of OS data in the IPME

The linkage between the occupational data to various IPME component models was previously discussed in Section **2**, e.g., *Table 2.2*. This section elaborates on this topic and describes in more detail how occupational data can be applied in IPME modelling. In particular, the section explains:

1. the enhancement of crew models using occupational characteristics;
2. the use of TSK statements to describe operator task requirements;
3. the creation of methodologies to evaluate manpower and personnel options.

In the end, a model of UAV operation was briefly described to demonstrate the application of the occupational data in a simulation experiment.

4.1 The role of occupational characteristics in operator modelling

The representation of the human operator is one of the central issues in human performance modelling. In computational human performance models, an operator is fundamentally an aggregation of a set of operator variables, each representing a particular characteristic. The list of possible operator characteristics is endless, however, only a finite set is included in a model based on the consideration that either a characteristic represents an independent variable that is subject to simulation manipulation or it is accountable, at least partially, for the variation of system performance.

In an IPME model, individual operators are represented independently and encapsulated in a crew model. By default, an operator is described by a set of commonly used characteristics, which are nominally classified into four categories. *Table 4.1* provides a definition for each category and some sample characteristics.

Table 4.1: Definition and examples of four categories of operator characteristics currently adopted in the IPME (adopted from the IPME user's guide [20])..

Category	Definition/examples
Property	the default physical characteristics for each operator, e.g., hand, foot, eyes
Anthropometry	independent and dependent measurements for the human body, e.g., Gender, percentile for operator measures, body measurement
Trait	non-physical operator personality characteristics that do not usually change as a consequence of simulation execution, e.g., agility and susceptibility to motion sickness
State	characteristics that are expected to change during the execution of a simulation, e.g., mental alertness, clothing, hunger

Following the IPME's convention, an operator characteristic consists of one or more attributes. A value or expression can be assigned to an attribute to indicate the status of the characteristic. A common naming format is "operator name.operator characteristic.attribute", such as Operator1.RightHand.Glove. As a variable, Operator1.RightHand.Glove can take on a binary

value to indicate whether or not gloves are worn by an operator: 1 (wear a glove) or 0 (no glove). These operator variables can be used in conjunction with environment and task network variables to determine decision logic and behaviour choices implemented in a model.

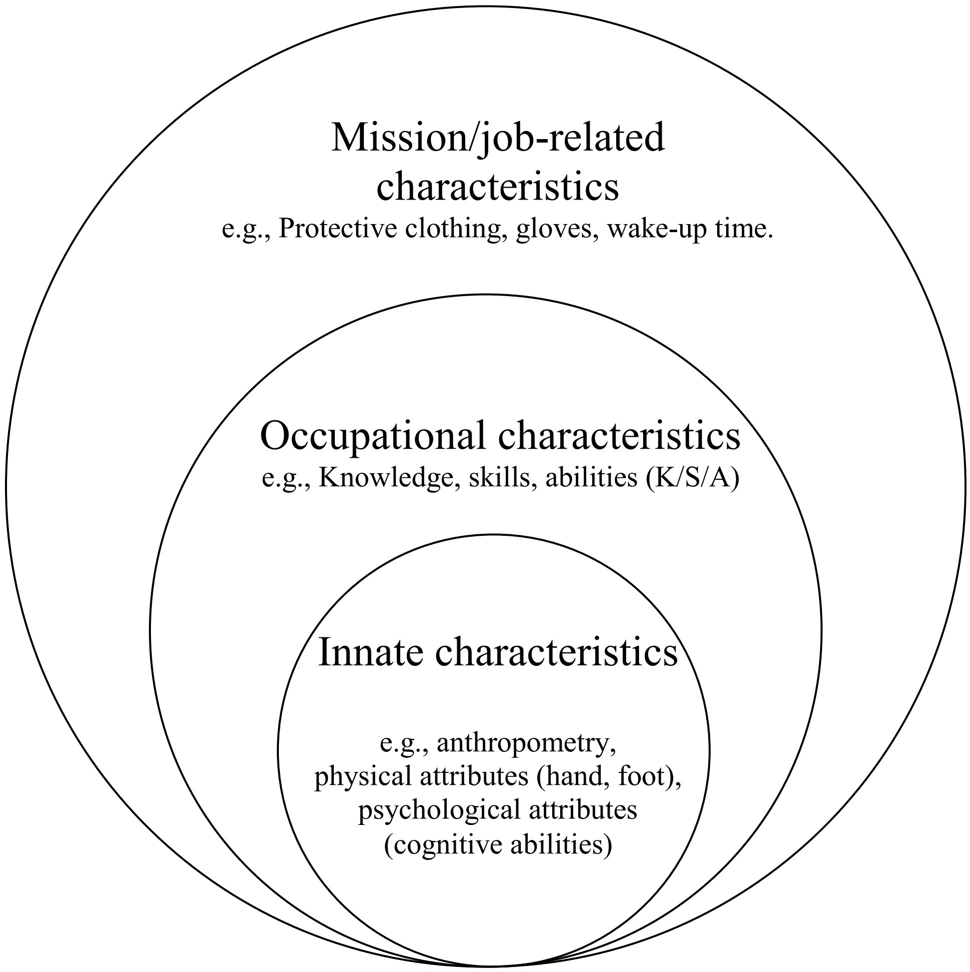

Figure 4.1: *An illustration of how occupational characteristics fit into existing IPME constructs for operator modelling.*

Prior to this project, the operators in an IPME model were primarily described by their innate (i.e., biological, physiological and psychological) and mission/job-related characteristics. Occupational information represents a new, medium, layer in operator modelling, as illustrated in *Figure 4.1*. These occupational characteristics are non-physical attributes that are not likely to be changed during the simulation timeline of a typical IPME model, therefore, following the definitions from *Table 4.1*, they are treated as operator traits.

4.2 Crew model

In the IPME, the creation of a new operator in a crew model can be achieved in two ways: by importing a previously saved operator model from a master database or by creating a new one from scratch. Either way, the operator's characteristics can be defined or modified on a standard

operator definition interface. In this project, a new “CF MOSID” tab was added to this interface, as shown in *Figure 3.4*, to allow an analyst to specify the operator’s occupation. The data associated with the occupation are then transferred into the IPME model.

For data security concerns, the OS databases are protected by a user password. When a modeller selects the “CF MOSID” tab, first an authorization window will pop up, requesting a password to access the OS data. After the permission is granted, the modeller maintains the access privilege during the rest of the session, that is, before the IPME shuts down.

Once a proper OS database is selected, the modeller can specify the operator’s occupation and job from two dropdown lists. The associated TSK attributes, grouped by duty areas, are then displayed in a pane using a collapsible tree format. Each TSK statement is associated with a check box. The modeller can either manually select/deselect each individual TSK entry, or automatically incorporate all available TSK attributes by using the “Check All” button. After the process is completed, the selected TSK attributes can be added to the operator model by a click of the “Add Checked” button. Technically, prior to this point, all actions are conducted solely within the OS databases. After the ‘Add Checked” button is pressed, these TSK attributes will be transferred into the IPME model. This process is not reversible, therefore a warning message is provided that reminds the modeller that future revision of the operator’s TSK attributes have to be conducted manually.

After the occupational information is added to the operator model, the operator is labelled with the specified occupation. Moving the mouse pointer to the operator icon will now trigger a tooltip that describes his/her occupational assignment. All selected TSK information is shown as traits which are also grouped under duty areas. A prefix of “MOSID_” is added to all occupational traits. These traits are global variables that can be accessed within the entire model.

The proficiency requirement provided in the performance requirement matrix is used by default as the mean value for each TSK attribute. This value is unitless and can be customised based on the model’s need. According to the IPME’s convention, it is possible to sample the value from an underlying distribution which is an important feature to simulate individual differences. The occupational traits are developed to support this capability. However, this construct is not used currently due to the lack of empirical evidence.

Once an operator model is completed, it can be replicated into multiple copies or deleted from the crew model. For future reuse, an operator model can also be exported to a master database.

4.3 Task network model

The occupational data can also be used in an IPME task network model. Two possible applications are illustrated here.

Firstly, the data can be introduced to characterize the requirements of a human task. The task network model is where human activities are defined. Prior to this project, each human task was described by its time parameters and the cognitive demand it imposed on an operator. With the addition of occupational data, it is now possible to describe a task in terms of its knowledge and skills requirements using the TSK descriptors obtained from the OS databases. Depending on the nature of the task, the TSK descriptors can be drawn from a repertoire that encompasses the entire spectrum of CF occupations. The requirement can be specified in either binary format (1-yes, 0-no) or using the 5-level proficiency rating scale.

Secondly, the operator's occupational traits can be used in scripts and embedded in task logic. For example, they can be used in task definition logic for adjusting task completion time, or in performance shaping function models for influencing error rate, as shown in two pieces of pseudo-code below. In addition, the occupational traits can be manipulated in combination with other model variables for addressing the questions that the model is designed to answer.

```
{
/* pseudo-code to demonstrate that if the assigned operator possesses the lowest
proficiency level for skill AS001, then the mean completion time for the current
task is increased by a factor T; */
        if(Operator1.Skill_AS001.value == 1) then
                meantime *=  T;
}

{
/* pseudo-code to demonstrate that depending on the operator's proficiency level
on hot refuelling (knowledge statement AK003), the error rate of such a task
varies */
        switch (Operator1.knowledge_AK003)
        {
                case (1): error_rate = epsilon1;
                          break;
                case (2): error_rate = epsilon2;
                          break;
                …
}
```

4.4 Output analysis methods

After the occupational characteristics are applied in an IPME model, the next step is to develop analytical methods for using this information in a simulation to achieve the ultimate project goal of addressing manpower and personnel issues. Three options, each with increased complexity and sophistication, are proposed and discussed.

The first option is essentially a structured gap analysis. The rationale is to compare the TSK requirements (captured in the task network model) to the TSK attributes possessed by the designated operators. A gap is identified when any mismatch between two sets of TSK statements occurs, and its impact is asymmetrical with different implications. If task requirements exceed operator capability (symbolized as $TSK_{req} > TSK_{operator}$), performance breakdowns and system failure are expected. On the other hand, if operator capability exceeds task requirements ($TSK_{operator} > TSK_{req}$), this is a case where the operator is considered over-qualified and the system performance will be protected. Although both cases are not ideal, their severity and resolution methods differ. The condition where $TSK_{req} = TSK_{operator}$ represents a theoretical optimum, and the eventual manpower or personnel solution will need to be further examined on a case-by-case basis.

The gap analysis is a simple approach, with the need of few assumptions. It does not attempt to make direct quantitative prediction of system performance. In principle, it can be conducted using the conventional pen-and-paper method. By incorporating the analysis in a model, there is an advantage to use simulation to gain better insights into mission requirements. For example, it is possible to identify critical tasks (i.e., tasks that reside on the critical path of the model's

operational sequence diagram) using simulation. Such tasks are essentially performance bottlenecks for a mission; the TSK requirements associated with these tasks should be prioritized and emphasized in operator training.

The second option extends the gap analysis and uses a Job Similarity Index (JSI) for measuring the appropriateness of operator assignment. Originally proposed by Farrell and Hubbard et al. [25], JSI is defined as a ratio between the number of matching TSK attributes an operator possesses and the total number of TSK attributes required by this operator's work. For example, if one operator's work can be fully described using 20 different TSK statements and the assigned operator holds 15 of them, then the JSI score of 0.75 (=15/20) is obtained. Farrell and Hubbard et al. [25] argued that relative JSI scores predict operator performance when the work is performed by individuals from different occupations without further training. A JSI score of one means the designated operator possesses all skills and knowledge that are required by the work; whereas a score of zero represents the opposite extreme where the designated operator has none of the required skills and knowledge. A higher JSI score is interpreted as a better match between work demands and occupational training. However, given the complex nature of human performance and the granularity of the current TSK data, it is difficult to use JSI for predicting absolute operator performance. Therefore, such an index is typically used to compare different levels of matching across alternative occupational options.

The concept of JSI can be easily integrated into IPME models. In Farrell, Hubbard and Culligan. [25], the TSKs were analyzed using a binary scheme, i.e., either the operator possesses a TSK attribute (1) or not (0), and the proficiency requirements were not included in the analysis. With computational support, it is possible to consider the proficiency requirements in JSI calculations which in principle can lead to models with an improved diagnostic power. In essence, the incorporation of different levels of proficiency requirement into a model enables the analysts to represent an operator's expertise more precisely. The usefulness of such information is reflected in two aspects. First, it can be used to model complex decision-making process and distinguish behavioural differences between novice and expert operators. For example, the naturalistic decision-making strategy can be introduced when the knowledge and skills level of an operator is sufficiently high. Second, such information can be applied in task performance prediction too. Very often, a reduction of task completion time and an increase of task accuracy can be expected by an operator with higher levels of knowledge and skills. The impact of occupational assignment on such a performance measure can be captured using standard IPME outputs. Notably though, the linkage between JSI scores and their performance implications needs to be fully validated. The task is challenging, given the generic nature of TSK statements currently adopted. Most likely, such linkage needs to be studied and validated in the context of specific projects.

The third option is the connection of occupational traits to common IPME MOPs like task completion time, the probability of performance breakdowns, and operator workload. Computationally, this option is already supported by the current software: as global variables, the occupational traits can be applied in, for example, performance shaping functions to affect system performance prediction. However, the challenge is to describe the impact of occupational traits on MOPs quantitatively. Further empirical evidence is needed before the formulation of such mathematical relationships becomes possible.

4.5 A modelling exercise

With the incorporation of occupational traits into the IPME model, analysts can now create operator models with increased precision and can use such models to examine manning and personnel options. To test this new capability, a modelling exercise was conducted to investigate

UAV operator selection. An IPME model of UAV operation was created and the TSK attributes were applied in this model. The JSI scores (i.e., the second approach described in the previous subsection where TSKs were analyzed in a binary scheme) were used as criteria for justifying operator choices. The exercise also examined an alternative approach for applying occupational data in human performance models, as adopted by the US Navy's Integrated Simulation Manpower Analysis Tool (ISMAT) program [26].

The UAV model was modified based on an IPME model previously developed for an intelligent and adaptive UAV control interface design project [27]. Three operator positions were considered, including a mission commander, a payload operator, and a vehicle operator. Their tasks were analyzed during a segment of a sixty-minute UAV operation scenario which involved primarily a surveillance mission using multiple UAVs.

Two models were created by using the IPME and ISMAT, respectively. For the IPME model, its task network reflected a streamlined version of the UAV model developed for the interface design project [27], and the knowledge and skills requirements for each operator task were assigned based on the database developed by Farrell, Hubbard and Culligan [25]. Three sets of operators were injected and tested in the model: the first set consisted of three air mobility navigators; the second set consisted of three maritime helicopter tactical control officers, and the third set represented a hypothetical case of a set of best possible operators who possessed all knowledge and skills of an air navigator (ANAV). In this case, the occupational assignment was entirely arbitrary and the decision to use ANAV was taken because its OS database was more complete compared with other occupations when the study was conducted.

The three sets of operators were plugged into the system model and the JSI scores were collected using self-defined snapshots enabled during the model's execution. The results found that none of the crew configurations were acceptable. Although the hypothetical best possible crew (the 3rd set) produced the highest JSI scores for all three roles, the levels of fit were still fairly low with JSI scores ranging between 25% and 35%. This indicated that the current knowledge and skills of an ANAV operator, as captured in the current database, were not sufficient to satisfy the needs of any of the three UAV operator positions. Between the first and second sets of operators, a maritime helicopter tactical control officer was found to be a better fit to all three roles than an air mobility navigator. The results demonstrated the feasibility to use JSI (i.e., the second approach described in Section **4.4**) for measuring the level of fit between operators and their tasks. The JSI scores were sensitive to operators' occupational assignment. Due to the incompleteness of the OS data, this exercise could not be considered as a formal validation and the results should not be interpreted literally. However, the study did verify the software platform and the modelling process, and proved at least the face validity of the model outputs.

For the ISMAT model, the effort focused on converting the UAV model and translating task requirements into a human skill taxonomy adopted by ISMAT. Due to the lack of access to the CF occupational databases, a direct comparison of its output to the IPME model was not possible. Therefore, the exercise focused on comparing the modelling process, examining the pros and cons of each approach, and identifying the future development needs for the IPME.

The study revealed a number of gaps between these two software platforms in handling manpower and personnel models. While a complete summary was provided in Lorenzen [22], an important issue is worth highlighting here. The access to the CF OS databases in the IPME model reflects an important first step to precisely represent CF personnel in a computational model. However, two obstacles still exist in the current capability. First, the TSK statements in the OS databases are mainly high level descriptors and there exist difficulties to automatically develop a

numerical link between these descriptors and operator task performance. This obstacle is especially significant when the occupational traits are used to quantitatively re-define a model's performance predictions (e.g., the third approach described in Section **4.4**). Second, the existing OS databases consist of hundreds of TSK statements. To effectively use this large amount of data, it requires the analysts to have a thorough understanding of the existing CF MOS. Such expertise is not available in the current modelling community. To address this issue, a possible solution is to incorporate a generic human skill taxonomy (e.g., [28]) for defining operator task requirements. Such a human skill taxonomy can be used to automatically translate operator task requirements into occupational TSK statements, which will reduce analysts' effort in applying occupational attributes during model construction and further improve the representation of operator characteristics in human performance models.

5. Discussion

This project has expanded DRDC's capability to address manpower and personnel issues using M&S. The integration of OS data into the IPME enables analysts to create human performance models that are sensitive to operator's occupational characteristics and support the analysis of manpower and personnel solutions in terms of their impact on system performance. The feasibility of this approach was demonstrated in a simulation exercise.

5.1 Known issues and limitations

The project also revealed several limitations. There are a number of remaining issues that need to be addressed in the future.

The OS data integration effort was constrained by both the incompleteness and the inconsistencies that existed in the current OS dataset. For example, the skill requirements were not complete for many occupations, and the definitions for the enumerated data types were not consistent across occupations. As a result, a single OS database consisting of the entire CF occupational information could not be created, which led to a reduction in system usability and an increased difficulty in database maintenance. This issue however is beyond the scope of the current project. It will be resolved with future CF effort to improve the OS data quality.

While the IPME model was repeatedly tested and iteratively developed in this project, it still has several usability issues. Firstly, the OS data are available to the analyst one occupation at a time; the inability to simultaneously search and compare OS data across occupations creates difficulty in model construction. Secondly, since each occupation is associated with a large number of TSK attributes, the task of choosing and mapping these data to a specific human task can be very tedious. Thirdly, the inclusion of a large set of occupational attributes in an IPME model can potentially have a big toll on model execution efficiency. This is often manifested in the model of a complex system with a large array of internal variables. Last but not the least is an issue associated with the modification of an operator's occupational assignment. Currently, when an operator's occupation is changed, his/her original TSK traits have to be removed manually. The IPME model does not have an internal representation of the linkage between occupation and the TSK traits; such information is available only in the OS database which is currently independent of the IPME model. As a work-around solution, it is suggested that a new operator model be created every time occupational changes are required and then to use the IPME's plug-and-play capability to assign the new model to the system. However, this is still a cumbersome solution and the issue should be addressed in the future.

The existing TSK requirement ratings need further validation. As noted in the occupational specifications, these ratings are intended as broad parameters for assisting activities like the creation of qualification standards or training plans. The validity of these ratings in the context of human performance modelling is not guaranteed. While this issue is not significant when a gap analysis (as explained in Section **4.4**) is applied, it becomes critical if these TSK ratings are applied in task logic definitions and/or the construction of performance-shaping functions.

The current modelling capability supports the representation of intra-occupational, but not inter-occupational, individual differences. In other words, the models of all operators assigned to the same occupation share the identical occupational traits. The levels of their training are modeled deterministically, i.e., without variances. This is acceptable at the current stage when the use of

M&S to resolve manpower and personnel issues is in the exploratory stage. However, the issue needs to be revisited when a more precise modelling of inter-operator differences are needed.

5.2 Future research and development

CF acquisition projects, as targeted in this project, represent one of many domains within which the manpower and personnel modelling capability can be applied. With the use of occupational information in human performance models, it is possible, for example, to apply M&S techniques in support of HR management activities.

One example is the use of human performance models for guiding the design and evaluation of new military occupations. This represents a "reverse engineering" way of thinking compared with the approach investigated and discussed in this project. Theoretically, it is feasible to study occupational performance requirements using simulation models that capture both task requirements and operator competencies. The approach is evidence-based and the results will be testable. Although arguably this approach may not be cost-effective when used to design an entire occupational specification, it is not far fetched to use it for addressing some components, e.g., TSK requirements, where alternative solutions are limited.

Another extension of IPME's modelling capability is to add cost functions into a model. Currently, system cost is not explicitly supported in IPME modelling. Since most existing IPME models focus on the design of the machine aspect of a system, the estimation of equipment cost is regarded as too difficult to model due to the large variances across models. Therefore, cost is often considered as a dimension outside of an IPME model's concern. With an extension to support manpower and personnel modelling, however, it is now possible to collect manpower cost data that can be re-used across projects. This is also in line with the common decision-making practices used in HR domains.

5.3 Conclusion

While it is widely recognized that the men and women in uniform are at the heart of the effectiveness of any military system, there exist many obstacles preventing the achievement of successful HSI. As sub-components of HSI, manpower and personnel solutions are no exceptions. It is not unusual to hear comments from system designers or engineers that insist user-centered requirements have limited utility until they have been translated into technical specifications of a system. The argument is that the operator, as an implicit component in a system, resides outside the design scope. Operator requirements therefore are treated as design constraints that need to be accommodated. This is one of the reasons why human factors practitioners are often viewed as critics in a design team.

While the cause of such a sentiment is multi-faceted, a more explicit representation of the human operator in a system may be able to alleviate the biased hardware-centric perspective. A possible solution is the use of M&S, especially during the early system design stage. Based on computational modelling, operators can be represented in a more tangible format and their needs can be examined with respect to their impact on system specifications.

This general goal was pursued by the current project. The improvement to the IPME model developed in the project reflects an expansion of DRDC's modelling capability to represent CF personnel with enhanced fidelity. The user can now create IPME models to conduct a broader spectrum of HSI analysis and address a wider range of human factors issues in system design and evaluation. The capability creates a potential bridge that connects M&S to the HR cycle of

activities. It provides an alternative approach to tackle manpower and personnel issues based on their system performance implications. Compared with conventional methods, it is now possible to examine manpower and personnel solutions, together with other aspects of system design, in an integrated fashion. To system designers and/or project decision-makers, the use of this modelling capability reflects an approach that is evidence-based, verifiable, and highly repeatable. It supports the generation of robust manpower and personnel solutions to deal with the challenges faced by the CF in future complex operational settings.

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Annex A A list of current CF occupations

Acronym	Occupation	MOSID	MOC
AC OP	Aerospace Control Operator	337	169, 170
ACS TECH	Aircraft Structures Technician	138	565, 566, 567, 568
AEC	Aerospace Control	184	39
AERE	Aerospace Engineering	185	41
AES OP	Airborne Electronic Sensor Operator	19	081, 082
AF ENGR	Airfield Engineering	189	46
AMMO TECH	Ammunition Technician	169	921
ANAV	Air Navigator	182	31
ARMD	Armour	178	21, 25, 26
ARTY	Artillery	179	22, 27, 28
ARTYMN – AD	Artilleryman – Air Defence	9	22
ARTYMN – FD	Artilleryman – Field	8	21
ATIS TECH	Aerospace Telecommunications and Information Systems Technician	109	226
AVN TECH	Aviation Systems Technician	135	514, 515, 516, 517
AVS TECH	Avionic Systems Technician	136	526, 527, 528
BE TECH	Biomedical Electronics Technologist	155	718, 736
BIO	Bioscience Officer	197	56
BOSN	Boatswain	105	181
CBT ENGR	Combat Engineer	339	43
CE SUPT	Construction Engineer Superintendent	307	649
CELE (AIR)	Communications and Electronics Engineering (Air)	340	83
CHAP (P)	Chaplain (Protestant)	200	61
CHAP (RC)	Chaplain (Roman Catholic)	201	62
CL DVR	Clearance Diver	342	341
COMM RSCH	Communicator Research	120	291
CONST TECH	Construction Technician	306	648
COOK	Cook	164	861
CRMN	Crewman	5	011, 012, 013
CRT RPTR	Court Reporter	322	833
DENT	Dental Officer	191	51
DENT TECH	Dental Technician	335	722, 725, 738
E TECH	Electrical Technician	125	331
ED TECH	Electrical Distribution Technician	302	642
EGS TECH	Electrical Generation Systems Technician	303	643
EME	Electrical and Mechanical Engineering	187	43
ENGR	Engineer	181	24
FCS TECH	Fire Control Systems Technician	327	434
FIRE FTR	Fire Fighter	149	651
FLT ENGR	Flight Engineer	21	91
GEO TECH	Geomatics Technician	238	142
HCA	Health Care Administration	192	48
HSO	Health Service Operations	193	52
HULL TECH	Hull Technician	124	321
IMAGE TECH	Imagery Technician	137	541

INF	Infantry	180	23
INFMN	Infantryman	10	31
INT	Intelligence	213	82
INT OP	Intelligence Operator	99	111
LCIS TECH	Land Communications and Information Systems Technician	110	227
LEG	Legal	204	67
LMN	Lineman	15	52
LOG	Logistics	328	78
MAR EL	Marine Electrician	126	332
MAR ENG ART	Marine Engineering Artificer	123	314
MAR ENG MECH	Maritime Engineering Mechanic	121	312
MAR ENG SYS OP	Marine Engineering Systems Operator	225	315
MAR ENG TECH	Marine Engineering Technician	122	313
MARS	Maritime Surface and Sub-Surface	207	71
MAT TECH	Material Technician	134	441
MED	Medical	196	55
MED TECH	Medical Technician	334	713, 716, 720, 721, 731, 732, 733, 737
MET TECH	Meteorological Technician	100	121
MLAB TECH	Medical Laboratory Technologist	152	714, 734
MP	Military Police	161	811
MPO	Military Police Officer	214	81
MRAD TECH	Medical Radiation Technologist	153	715, 735
MS ENG	Marine Systems Engineering	345	88
MSE OP	Mobile Support Equipment Operator	171	935
MUS	Music	210	75
MUSCN	Musician	166	871
NAV COMM	Naval Communicator	299	277
NAV ENG	Naval Engineering	346	89
NCI OP	Naval Combat Information Operator	114	275
NCS ENG	Naval Combat Systems Engineering	344	87
NDT TECH	Non-Destructive Testing Technician	343	532
NE TECH(A)	Naval Electronics Technician (Acoustic)	116	283
NE TECH(C)	Naval Electronics Technician (Communications)	117	284
NE TECH(M)	Naval Electronics Technician (Manager)	119	286
NE TECH(T)	Naval Electronics Technician (Tactical)	118	285
NES OP	Naval Electronic Sensor Operator	115	276
NUR	Nursing	195	57
NW TECH	Naval Weapons Technician	17	65
PAO	Public Affairs Officer	203	66
PH TECH	Plumbing and Heating Technician	304	646
PHARM	Pharmacy	194	54
PHY TH	Physical Therapy	190	49
PID	Port Inspection Diver	226	345
PLT	Pilot	183	32
POST CLK	Postal Clerk	167	881
PSEL	Personnel Selection	208	72

RM TECH	Refrigeration and Mechanical Technician	301	641
RMS CLK	Resource Management Support Clerk	298	836
SAR TECH	Search and Rescue Technician	101	131
SIG OP	Signal Operator	329	215
SIGS	Signals	341	84
SOCW	Social Work	198	58
SONAR OP	Sonar Operator	324	278
STWD	Steward	165	862
SUP TECH	Supply Technician	168	911
TFC TECH	Traffic Technician	170	933
TRG DEV	Training Development	211	74
VEH TECH	Vehicle Technician	129	411
W TECH L	Weapons Technician (Land)	130	421
WFE TECH	Water, Fuels and Environment Technician	305	647

List of symbols/abbreviations/acronyms/initialisms

CAMA	Canadian Air Force MOSID Administration tool
CF	Canadian Forces
CONOPS	Concept of Operations
DND	Department of National Defence
DRDC	Defence Research and Development Canada
GS	General Specification
GUI	Graphical User Interface
HR	Human Resources
HSI	Human Systems Integration
IPME	Integrated Performance Modelling Environment
ISMAT	Integrated Simulation Manpower Analysis Tool
JSI	Job Similarity Index
M&P	Manpower and Personnel
M&S	Modelling and Simulation
MANPRINT	Manpower And Personnel Integration
MOC	Military Occupational Code
MOE	Measure of Effectiveness
MOP	Measure of Performance
MOS	Military Occupational Structure
MOSART	Military Occupational Structure Analysis, Redesign, and Tailoring project
MOSID	Military Occupational Structure Identification Code
NATO	North Atlantic Treaty Organization
NCM	Non-Commissioned Member
NCMGS	Non-Commissioned Member General Specification
NF	Normal Form
NOC	National Occupation Classification
OGS	Officer General Specification
OS	Occupational Specification
TSK	Tasks, Skills, and Knowledge
UAV	Uninhabited Aerial Vehicle
US	The United States

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(U) The addition of occupational information into a human performance modelling environment enables the creation of human performance models that are sensitive to operator's occupational attributes. Such models can be used to address manpower and personnel issues frequently encountered in military system design and evaluation. A recent applied research project was conducted to incorporate the Canadian Air Force occupational data into the Integrated Performance Modelling Environment (IPME). This project expanded Defence Research and Development Canada (DRDC)'s modelling capability and enabled analysts use modelling and simulation to examine manpower and personnel solutions in future Canadian Forces (CF) acquisition projects. The report recaps major activities in this project, including occupational data integration, software implementation, and the application of the occupational data in IPME models.

(U) L'ajout de données sur les groupes professionnels militaires dans un environnement de modélisation du rendement humain permet de créer des modèles de rendement humain qui sont adaptés aux caractéristiques professionnelles d'un opérateur donné. Ces modèles peuvent être utilisés pour résoudre les problèmes liés à la main d'œuvre et au personnel que l'on rencontre souvent lors de la conception et de l'évaluation des systèmes militaires. On a récemment mis en œuvre un projet de recherche appliquée afin d'intégrer des données sur les groupes professionnels militaires des Forces canadiennes (FC) dans l'Environnement intégré de modélisation du rendement (EIMR) / Integrated Performance Modelling Environment (IPME). Ce projet a permis d'augmenter les capacités de modélisation de Recherche et développement pour la défense Canada (RDDC) et a permis aux analystes d'utiliser la modélisation et la simulation pour examiner les solutions aux problèmes de main d'œuvre et de personnel dans les futurs projets d'acquisition des Forces canadiennes (FC). Le rapport récapitule les principales activités menées dans le cadre de ce projet, y compris l'intégration des données sur les groupes professionnels militaires, la mise en œuvre du logiciel et l'application des données sur les GPM dans les modèles de l'EIMR.

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(U) Manpower, Personnel, Human systems integration, Modelling and simulation, IPME, Occupational specification, Human performance modelling

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